Climatic Changes in Space Weather: Sustained Minima and Maxima in Solar Activity

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RAL Space

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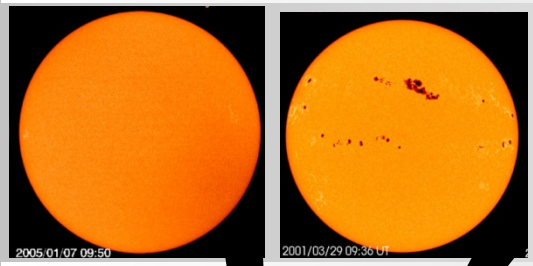
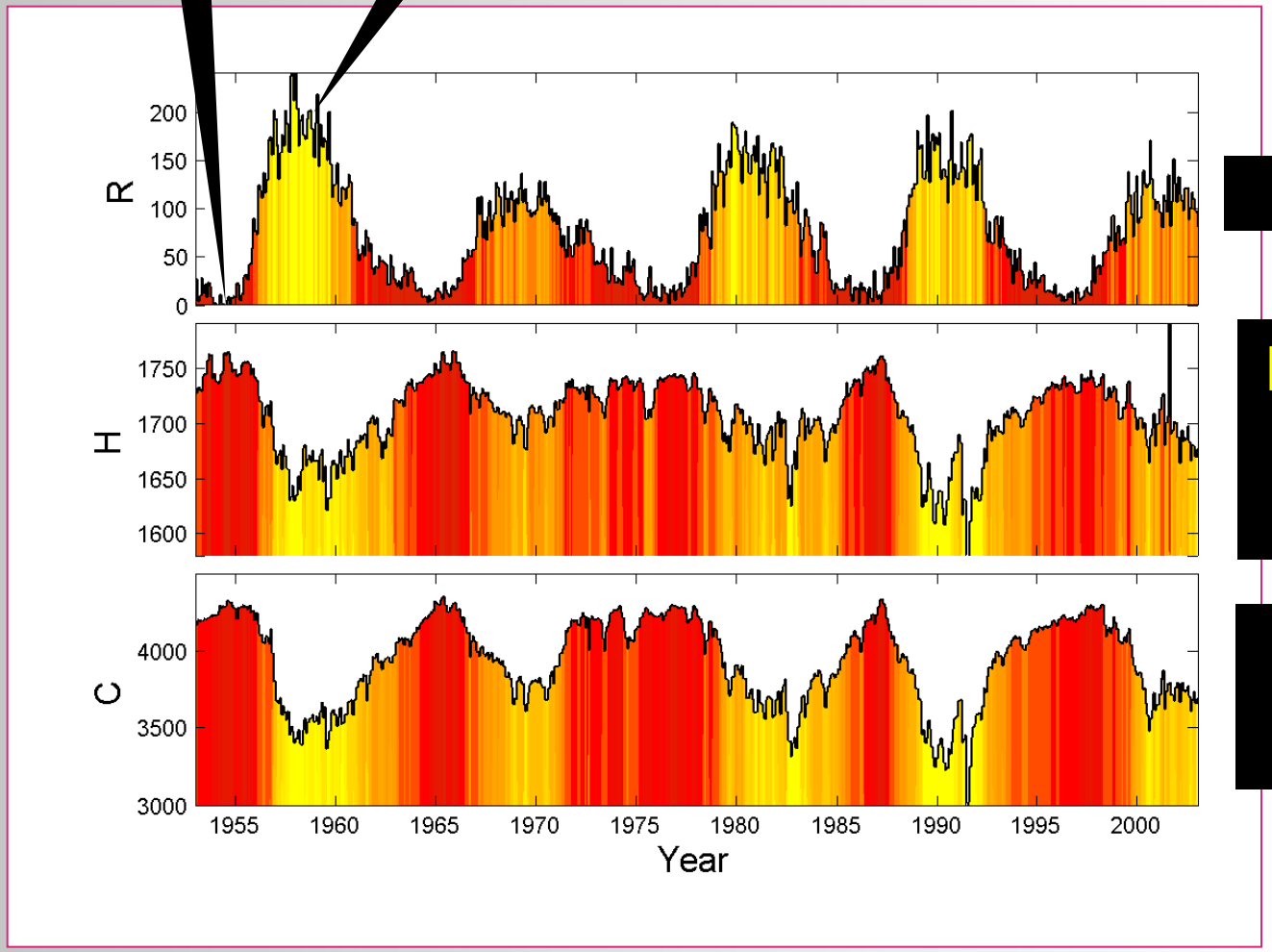
- Mike Lockwood
- Luke Barnard
- Chris Davis (also at RAL Space)



Cosmic Rays

Anticorrelation with sunspot numbers

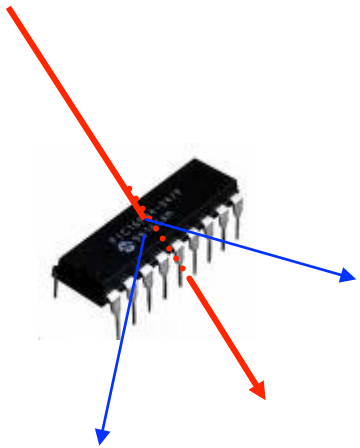


Sunspot Number

Huancauyo – Hawaii neutron monitor

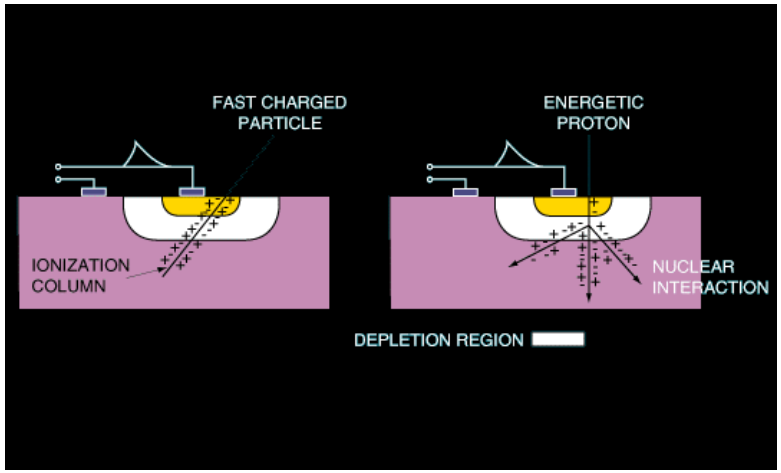
Climax neutron monitor counts (>3GV)

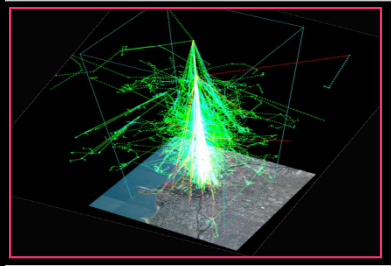
Why does this matter?



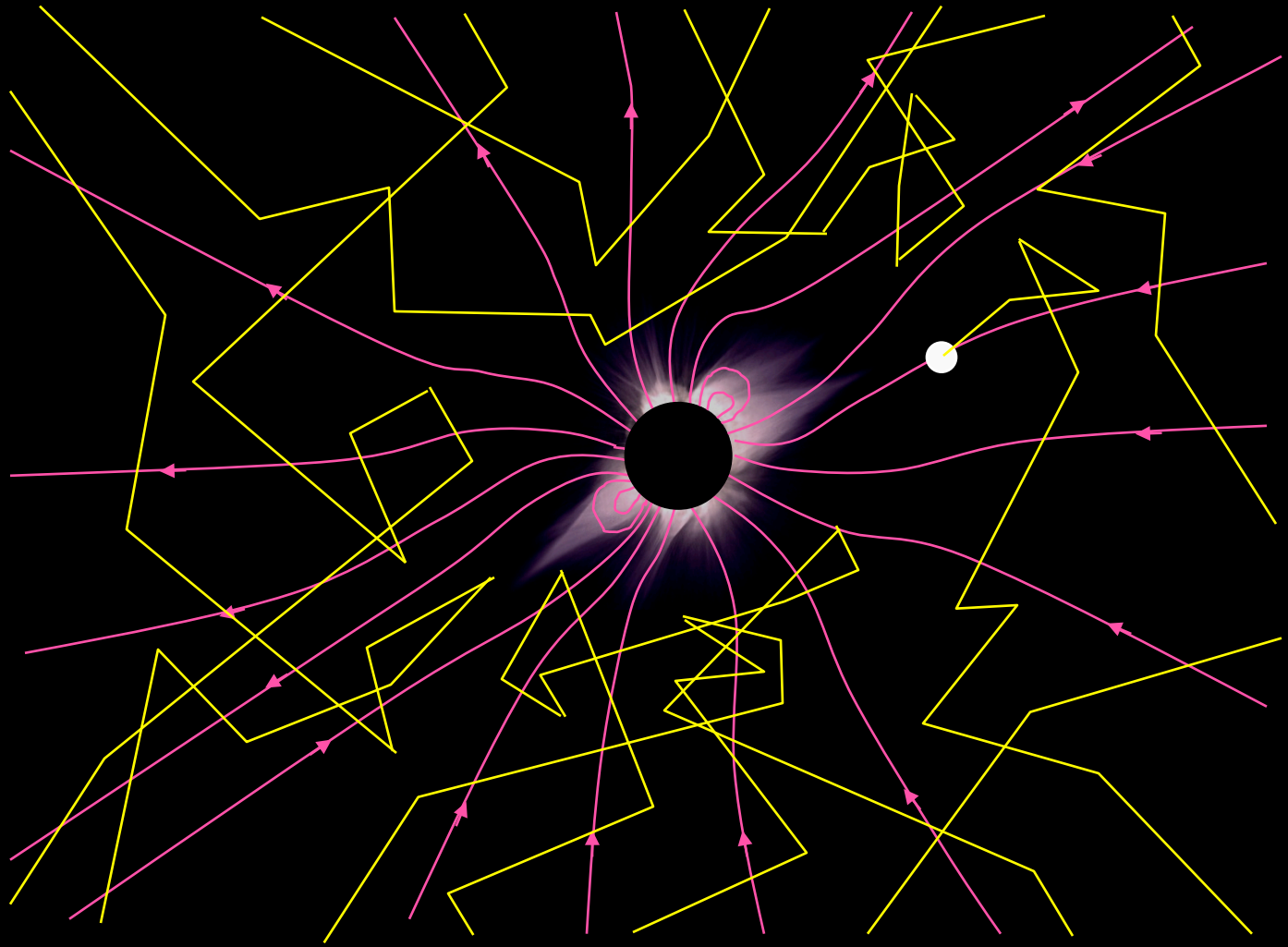
- Cosmic rays penetrate electronics
  - Single event effects: ionisation, bit flips, latch-up, …
  - Wear & tear: nuclear reactions – damage structure
  - Also from solar radiation & rad belts

- Seen in space, aircraft & ground systems
  - Major design constraint
  - Need environmental specification
- Also health issue for aviation



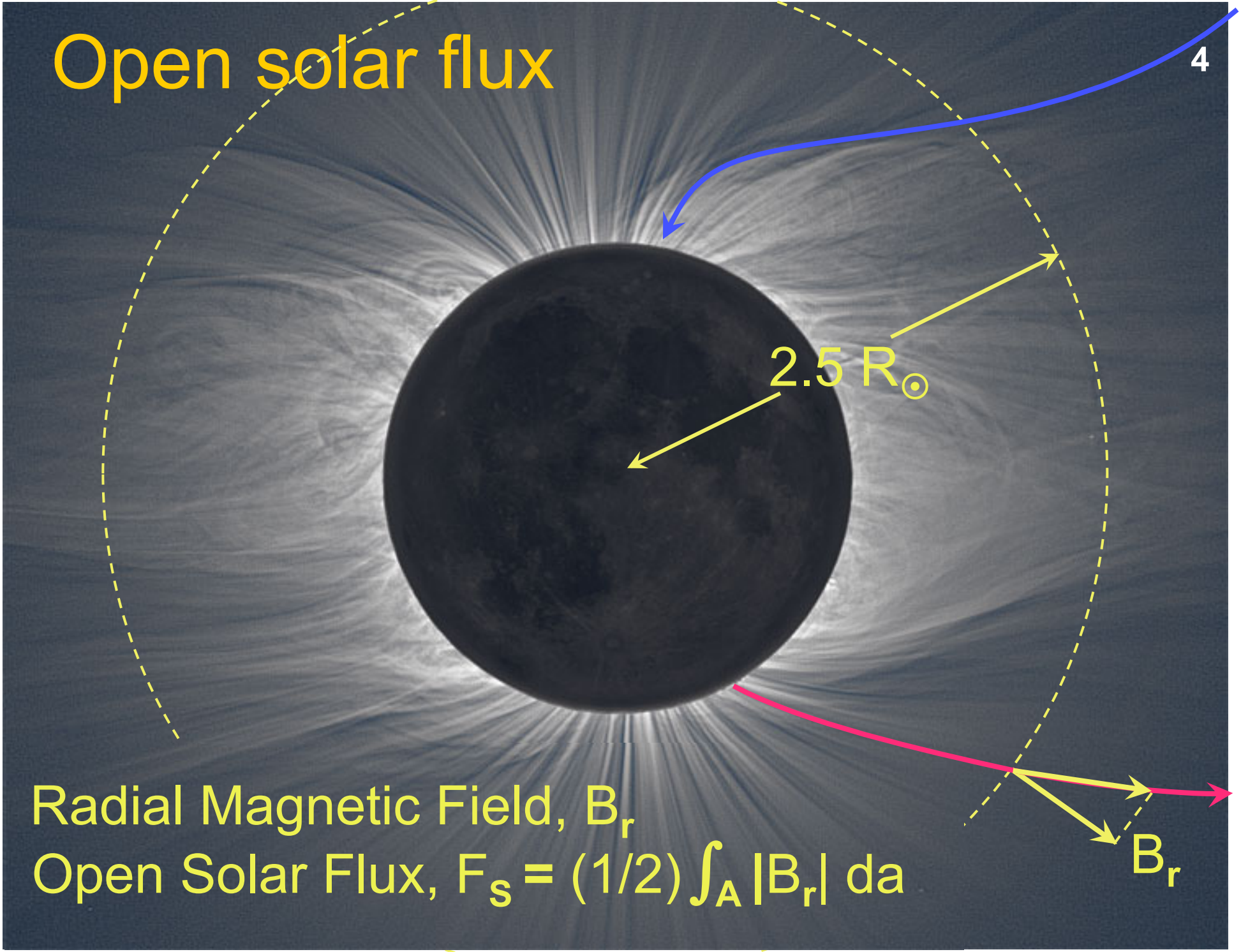


Galactic Cosmic Rays



The coronal source flux is dragged out by the solar wind flow to give the heliospheric field which shields Earth from galactic cosmic rays

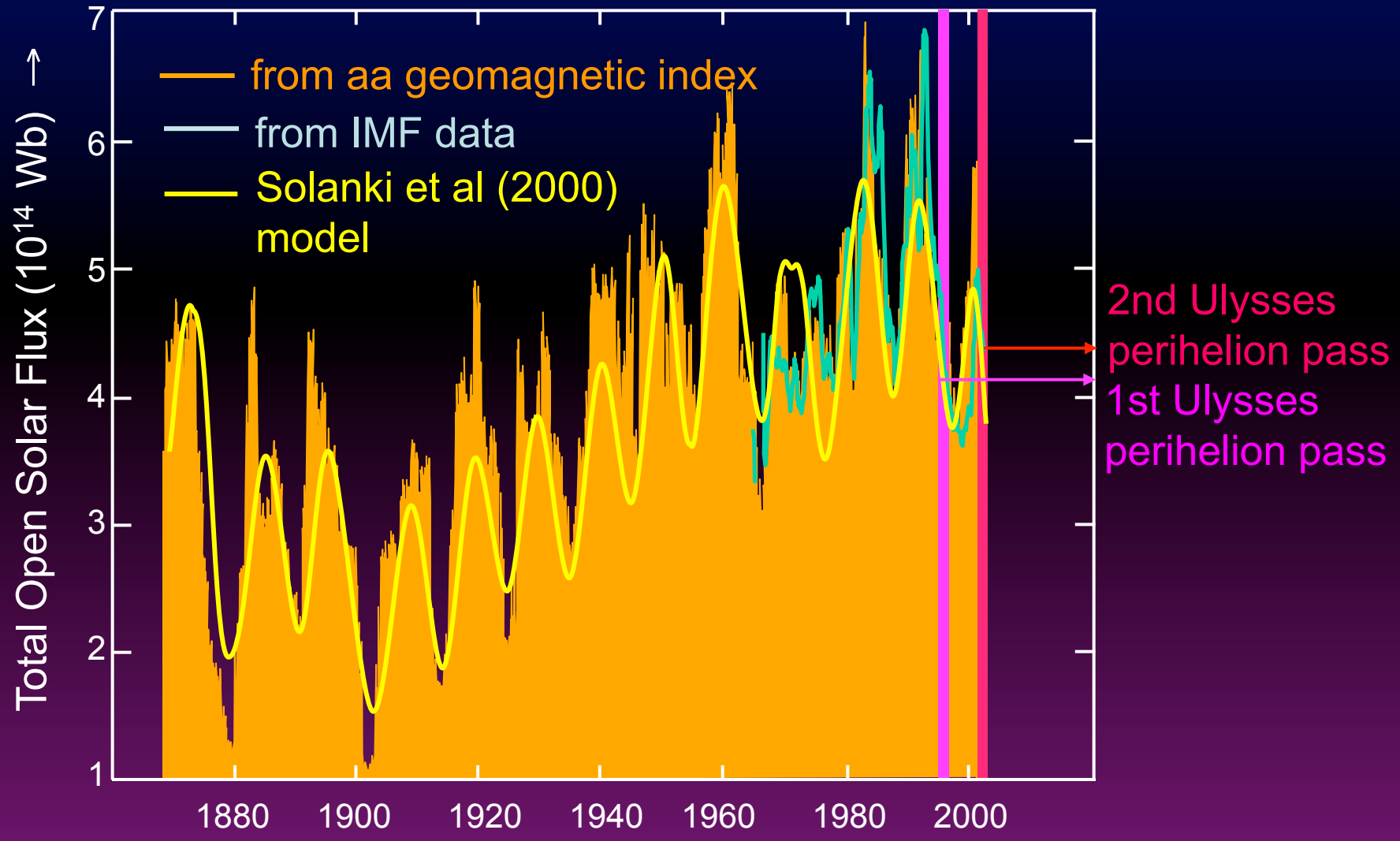
Open solar flux



Radial Magnetic Field, B_r

Open Solar Flux, $F_s = (1/2) \int_A |B_r| \, da$

Long-term variation of open solar flux



(deduced from Ulysses result that radial field is independent of solar latitude)

^{14}C & ^{10}Be: spallation products from O, N & Ar

RAL Space

^{14}C

- $\tau_{1/2}$ = 5370 yr

GALACTIC COSMIC RAYS

^{10}Be

- $\tau_{1/2}$ = 1.5×10^6 yr

STRATOSPHERE

$^{14}C + O \rightarrow {}^{14}CO$; $^{14}CO + OH \rightarrow {}^{14}CO_2 + H$

TROPOSPHERE

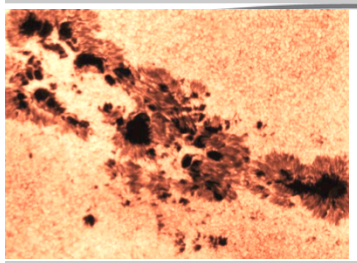
(~1 year) *(~1 week)*

OCEANS

^{10}Be + AEROSOL

BIOMASS

ICE SHEETS

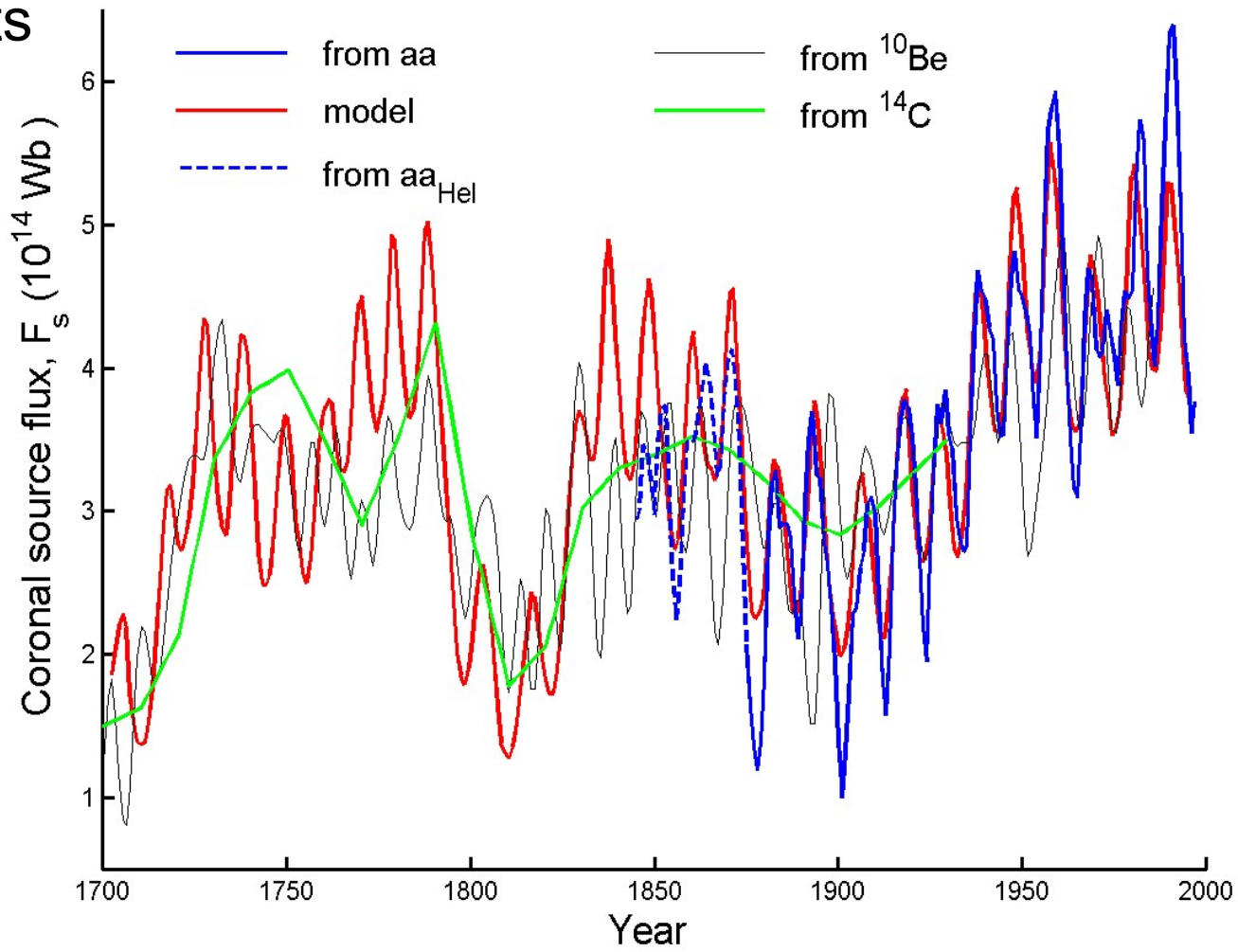


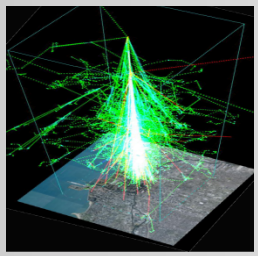
Open Solar Flux Variation

(Viera and Solanki, 2009; Lockwood et al., 2009, 1999)

OSF model fits with:-

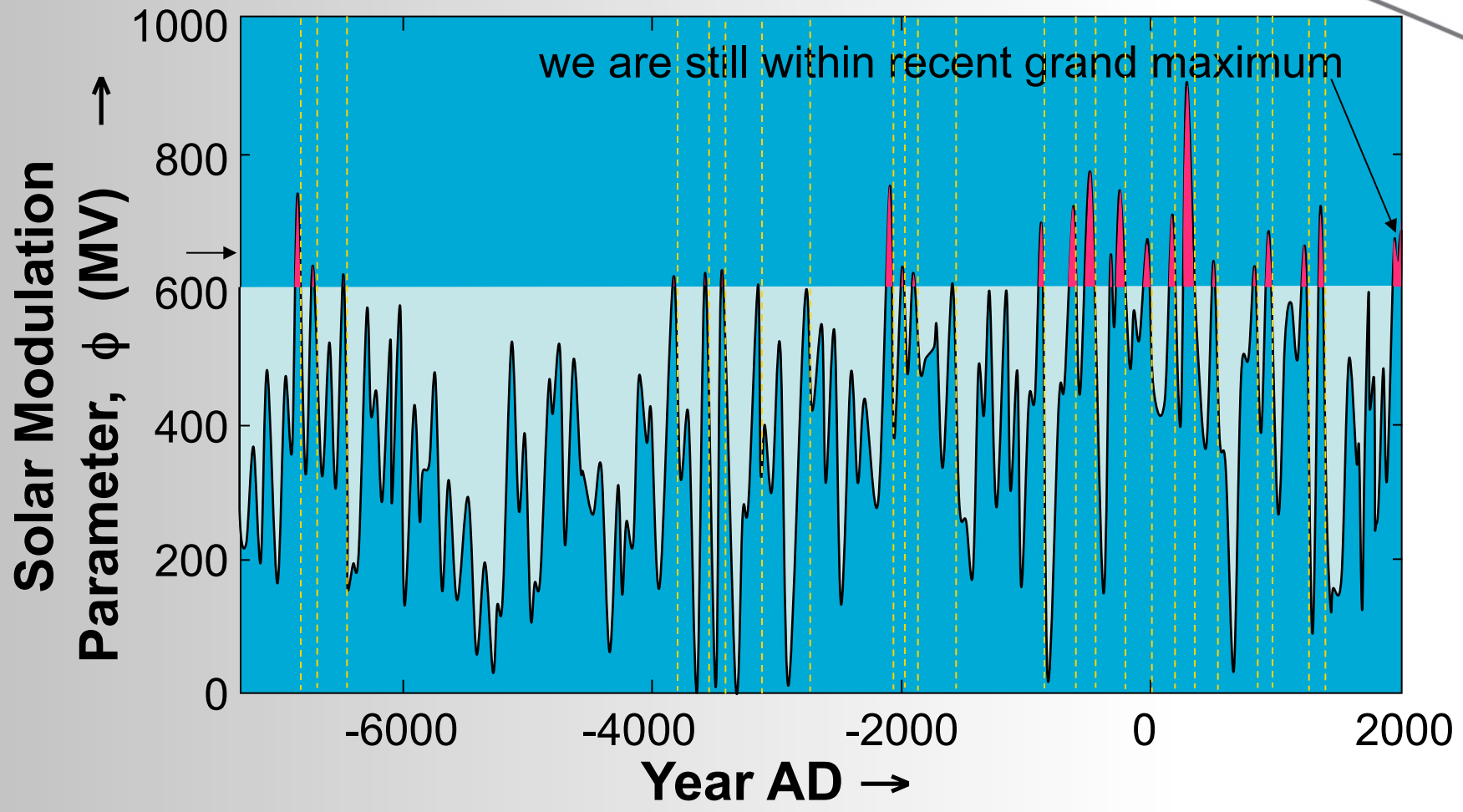
- the aa geomagnetic index
- ^{10}Be abundance in ice sheets
- ^{14}C abundance in tree trunks



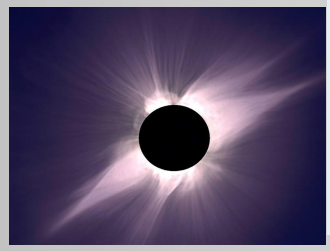


Millennial Variation

ϕ composite (25-year means) from cosmogenic isotopes by Steinhilber et al. (2008)

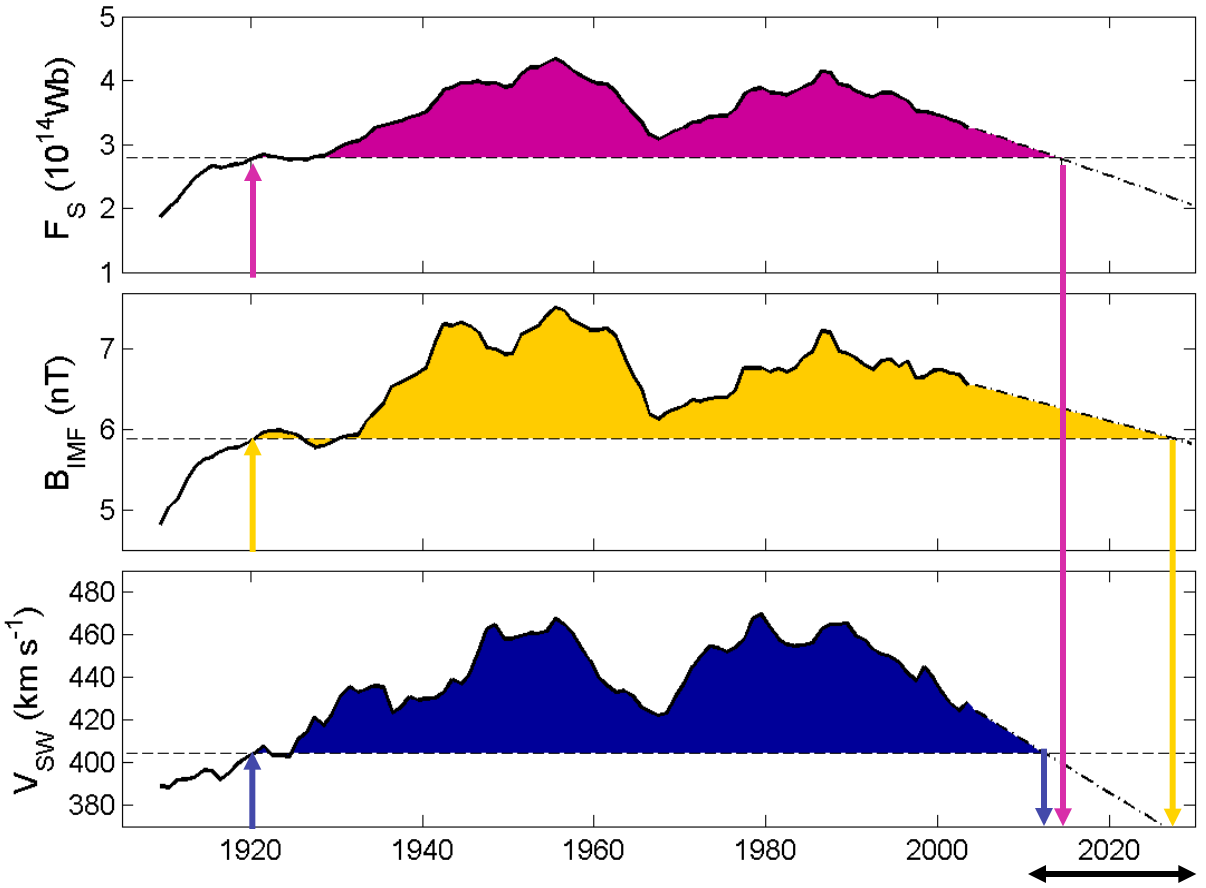


composite from Solanki et al., 2004; Vonmoos et al., 2006 & Muscheler et al., 2007

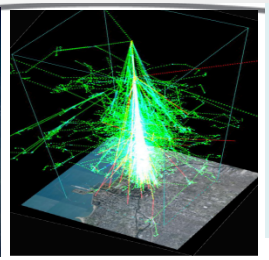


Centennial Variations: the rise and fall of the current grand maximum (GSM)

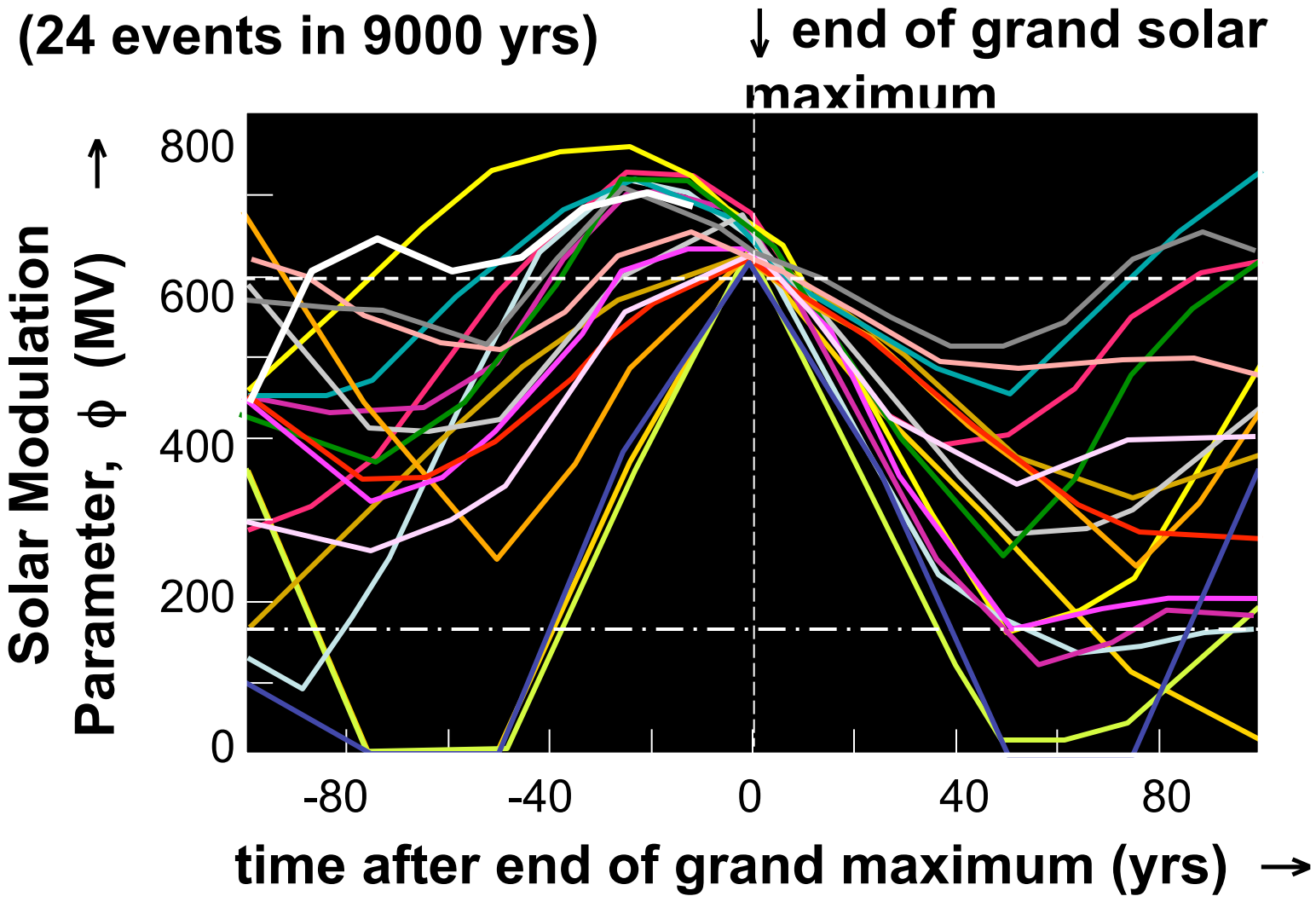
- solar cycle running means
- defining GSM by ϕ > 600 MV it began in 1920
- linear extrapolation gives end dates consistent with GSM durations

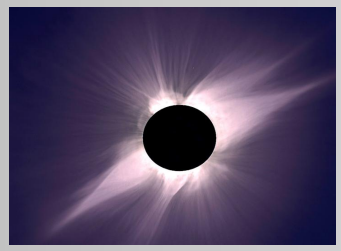


Abreu et al. (2008)



Superposed epoch study of the end of grand maxima





Future Variations

(Barnard et al., 2011)

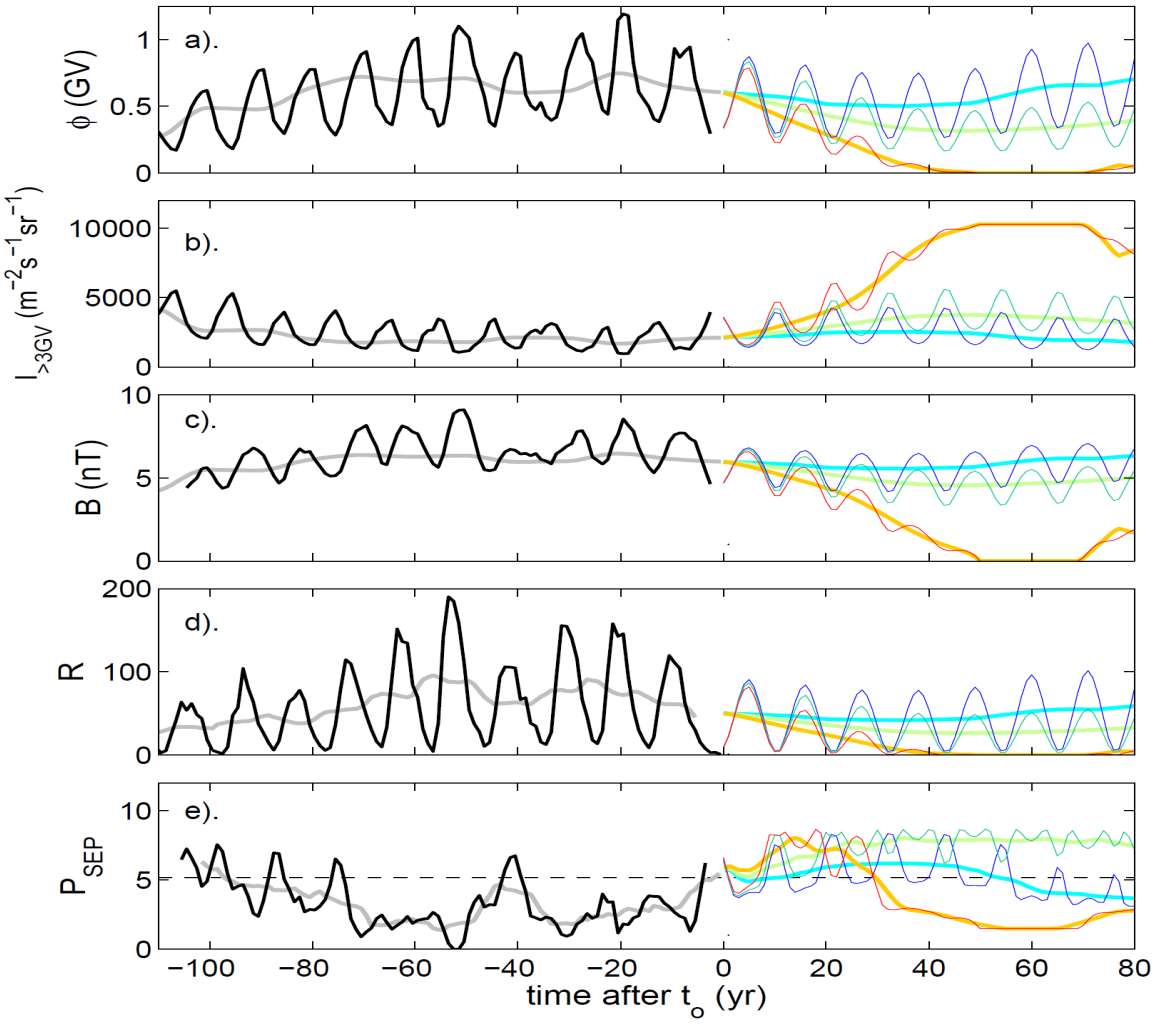
♣Solar modulation parameter, ϕ

♦>3GV GCR flux

♥ IMF field strength, B

♠Sunspot number, R

♣ Probability of a large SEP event, $P_{SEP}(10^{-2}\ yr^{-1})$



Summary 1

- Natural decline of solar activity in 21st century
- Cosmic ray fluxes increasing in space & aircraft cruise altitudes
  - factor 2 to 4 increase over next 40 years
  - increased SEU risk + human rad dose
- Increasing probability of very large radiation storms (≥30% Carrington intensity)
  - Spacecraft probably survive (Odenwald studied 3 x Carrington; unsellable to risk managers)
  - But wider regulatory implications poorly studied: single event dose >> 1 mSv, especially at cruise altitudes
  - Aviation impact ~ Eyjafjallajökull?
  - Ground impacts?? Potential for chaotic response?

Summary 2

- Many other long-term trends need study
  - Decline in geomag field (~10-15% over past 150 yrs)
  - Greenhouse gas impacts on upper atmosphere (right)
  - Solar change & geomagnetic activity
- Bottom line
  - Forward modelling essential (lesson from insurance)